(Revised 07/09)

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(please insert ref. above)

NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Experimental Investigation of the Local Balance Between Buoyant and Inertial Forces in Turbulent Thermal Convection

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Xia, Ke-Qing	Prof. Zhou, Quan
Post	Professor	Professor
Unit / Department / Institution	Physics Department, The Chinese University of Hong Kong	Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University
Co-investigator(s) *(with title)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1/1/2012		
Project Completion date	31/12/2014		
Duration *(in month)*	36		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To investigate the mechanism of velocity and temperature cascades in turbulent thermal convection by measuring the scale-dependence of the buoyant force and the inertial force in the inertial range.

2. To measure the energy dissipation rates and to determine the local Kolmogorov dissipative length scale $\eta(x)$.

3. To measure the thermal dissipation rates and, by combining results from above, to determine the local Bolgiano length scale $L_B(x)$.

5.2 Revised Objectives

Date of approval from the RGC: N/A

Reasons for the change:

1.

2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Our investigation of the local and global Bolgiano length scale L_B have revealed a rather complex behavior for this important length scale in thermally-driven turbulence, which is the length scale that separates the buoyancy-dominant and inertia-dominant regimes. Specifically, we found that the locally averaged Bolgiano scale is highly spatially inhomogeneous and anisotropic. Its value reaches a minimum value near the isothermal top and bottom plates as well as near the adiabatic sidewall region, while increases towards the core region of the convection cell. Another important finding is that the local Bolginao scale reaches a minimum for moderate values of the Rayleigh number Ra. This feature holds for different values of the Prandtl number Pr investigated. The results provide important information regarding the best parameter range in the Pr-Ra phase diagram to search for the long sought-after Bolgiano-Obukhov (BO59) scaling. For example, for water (Pr ~ 4) our results suggest that Ra ~ 10^8 should be the best value to search for the BO59 scaling.

Our study of both the kinetic energy dissipation rate ε_u and thermal dissipation rate ε_T further reveal that the observed behavior of the Bolgiano scale is a result of interplay between ε_u and ε_T, as L_B depends on both quantities. The joint PDF of the energy and thermal dissipation rates shows that high values of ε_u and ε_T tend to occur together. Moreover, the conditional average of the local vertical heat flux in the core region of the flow reveals that the highest vertical heat flux occurs for rare events with very high dissipation rates, while the joint most probable dissipation rates are associated with very low values of vertical heat flux.

Whereas the Ra-dependence of local Bogiano scale shows a minimum value, the local Kolmogorov dissipative length scale $\eta(x)$ exhibits a monotonic decrease with increasing Ra over the range of Ra investigated. The local Kolmogorov scale also remains smaller than the Bolgiano scale for all values of Ra.

Our investigation of the mechanism of velocity and temperature cascades through the velocity and temperature structure functions show that the longitudinal velocity structure function in the vertical direction appear to approach a K41-like scaling, while the temperature structure functions in the vertical direction, on the other hand, tend to approach a BO59 scaling for scales greater than the local Bolgiano scale. We also examined the mixed velocity and temperature structure function and found that the mixed vertical velocity–temperature structure function appears to approach the scaling predicted by BO59 for a small range above the local Bolgiano scale.

Our direct measurement of the buoyant force and inertial force show that over a limited range of the separation scale the quantities exhibit comparable magnitude and scale dependence, and therefore an approximate balance exist between the two forces.

Our experimental study of the Kolmogorov constants showed that they have a very strong dependence on the Reynolds number Re and approach to constant values only for extremely high values of Re that is usually unattainable in laboratory experiment, as well as in most present numerical experiments. In our study of pair dispersions we found an exponential growth of the separation between a pair of particles predicted by Batchelor long time ago. A cross over from Batchelor to Richardson regimes is also observed.

Potential for further development of the research and the proposed course of action *(maximum half a page)*

There are a number of possible lines of research that one can develop from the wealth of information and knowledge obtained from the present project. For example, to extend the observable range of the BO59 scaling, one can extend the horizontal scale of the system while maintaining a moderation value of Ra by using large aspect ratio convection cells. Another interesting area arising from the pair dispersion study is to investigate backward dispersion that is important for a range of applications but few experimental studies exist. To proceed, we plan to apply research funding these lines of research, among others.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

The natural phenomenon of convection plays a vital role in the dynamics of many geophysical and astrophysical systems as atmospheric and oceanic convections in the Earth, and stellar convections such as that in the Sun. The Rayleigh-Bénard (RB) convection, a fluid layer heated from below and cooled on the top, is arguably the simplest system to model the convection problem occurring in nature.

A long-standing issue in the study of turbulent thermal convection has been what is the mechanism that drives the velocity and temperature cascades? Some say it should follow the traditional Kolmogorov picture of energy cascade, i.e. turbulent kinetic energy is injected in the large scale and then cascades to the small scale. Others argue that it should follow the so-called Bolgiano-Obukhov picture, which states that energy is injected at every scale via buoyancy above the so-called Bolgiano scale and then cascades to small scales. In this work, we have shown that the Bolgiano scale increases rapidly with the Rayleigh number Ra after certain value and therefore to search the Bolgiano-Obukhov scaling one needs to work with a moderate value of Ra.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.))

The Latest Status of Publications				Author(s) *(**bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*					
2013				**Matthias Kaczorowski** and **Ke-Qing Xia***	Turbulent flow in the bulk of Rayleigh-Bénard convection: small-scale properties in a cubic cell/ J. Fluid Mech. vol. 722, pp. 596-617	Yes	No	Yes

2013				**Quan Zhou** and **Ke-Qing Xia***	Thermal boundary layer structure in turbulent Rayleigh_Bénard convection in a rectangular cell/J. Fluid Mech. vol. 721, pp. 199-224	Yes	No	Yes
2013				**Rui Ni** and **Ke-Qing Xia***	Experimental investigation of pair dispersion with small initial separation in convective turbulent flows / PHYSICAL REVIEW E **87**, 063006	Yes	No	Yes
2013				**Rui Ni** and **Ke-Qing Xia***	Kolmogorov constants for the second-order structure function and the energy spectrum / PHYSICAL REVIEW E **87**, 023002	No	Yes	Yes
2013				**Ke-Qing Xia***	Current trends and future directions in turbulent thermal convection/ THEORETICAL & APPLIED MECHANICS LETTERS **3**, 052001	No	YES	YES

2014				**Matthias Kaczorowski, Kai-Leong Chong and Ke-Qing Xia***	Turbulent flow in the bulk of Rayleigh-Bénard convection: aspect-ratio dependence of the small-scale properties /J. Fluid Mech., vol. 747, pp. 73_102	No	YES	YES

9. Recognized International conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*
Aug./2012/ Beijing	Analysis of the Bolgiano length scale in the bulk of turbulent Rayleigh-Benard convection	23rd International Congress of Theoretical and Applied Mechanics	No	Yes	Yes
Sept/2013/ Lyon	Energy Dissipation Rate, Velocity Correlation Function and Structure Functions in Turbulent Rayleigh-Bénard Convection with Polymer Additives	The 14th European Turbulence Conference	No	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Yi-Chao Xie	PHD	Aug. 2012	Aug. 2015 (expected)
Kai-Leong Chong	MPhil	Aug. 2012	Aug. 2014

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

Mr. Kai-Leong Chong has been awarded the Hong Kong PhD Fellowship (2014-2017). His MPhil thesis work was support by the present project. Part of the results was published in J. Fluid. Mech. in 2014 (Publication # 6).